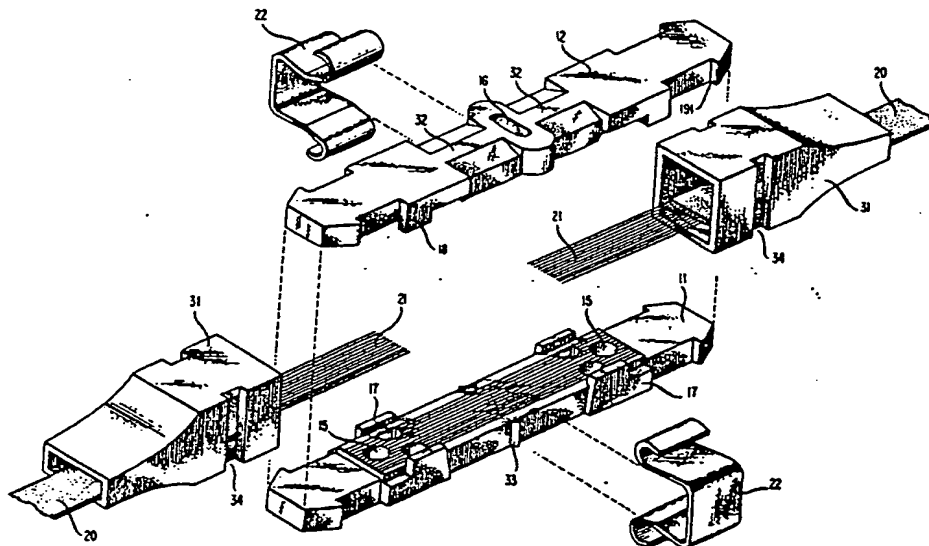




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(54) Title: OPTICAL FIBER CONNECTOR AND ARTICLES CONNECTED THEREWITH



(57) Abstract

An optical fiber connector of the continuous groove type comprising a substrate (11) with a multiplicity of fiber-receiving grooves (13) thereon, and a cover member (12) comprising compliant fiber-contacting material having a modulus of elasticity less than about 10^6 psi (less than about 6.9 GPa), preferably less than 10^5 psi. Connectors according to the invention can have low loss, and low added loss during thermal cycling. In a particular preferred embodiment, the substrate is a molded plastic part, and the compliant material is an adhesive-backed polyester film.

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OPTICAL FIBER CONNECTOR AND
ARTICLES CONNECTED THEREWITH

Field of the Invention

5 This invention relates to optical fiber
connectors.

Background of the Invention

Optical fiber communication systems are rapidly
being commercialized. Essentially all such systems require
10 means for catenating fibers, and such means will be
referred to herein as connectors.

The industry has expended a substantial effort to
develop fiber connectors, and this effort has resulted in
disclosure of a variety of connector types. One of these
15 types, to be referred to as the continuous groove
connector, comprises fiber-receiving grooves in a
substantially plane substrate, with pairs of fibers to be
connected placed end to end into the grooves, and
maintained therein by a cover member. U. S. Patent
20 Nos. 3,912,574 and 4,028,162, disclose respectively a
continuous groove connector and a method for splicing fiber
by means of the connector. U. S. Patent No. 4,146,301
discloses a continuous groove connector with vacuum slots.

Optical fiber connectors typically are expected
25 to meet several demanding criteria. Among these are low
loss and good thermal stability, i.e., little added loss
due to temperature changes. Other criteria of interest
are rapid and easy assembly requiring little skill, and low
cost. Among the above criteria, at least achievement of
30 thermal stability has proven problematical in prior art
continuous groove connectors.

Because connectors of the continuous groove type
are potentially very desirable for a variety of
applications, especially for splicing ribbon cables, a
35 continuous groove connector that has good thermal
stability, while also possessing the other desirable
characteristics referred to above, would be of substantial

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interest. This application discloses such a connector.

Summary of the Invention

The inventive optical fiber connector comprises a substrate, at least one cover member, and means for
5 securing the cover member to the substrate. The substrate comprises at least one fiber-receiving groove into which a portion of a first optical fiber and a portion of a second optical fiber are to be placed such that an end of the first fiber is facing an end of the second fiber. The
10 cover member comprises material which is to be in contact with at least the first fiber, the material to be termed fiber-contacting material, the fiber-contacting material being compliant, having a modulus of elasticity that is less than about 10^6 psi (less than about 6.9 GPa),
15 typically less than about $2 \cdot 10^5$ psi, preferably less than 10^5 psi, at 25°C. The optical fiber connector also comprises cover-securing means adapted for urging the cover member towards the substrate such that the fiber-contacting material is maintained in contact with the fibers.

20 In preferred embodiments of the invention, the cover member comprises a backing member comprising material having a modulus of elasticity that is substantially greater than the modulus of the fiber-contacting material, with the fiber-contacting material
25 attached to the backing member. The fiber-contacting material is, for instance, an adhesive-backed polymeric film, e.g., a polyester film. Also, the substrate preferably comprises a grooved member having a multiplicity of substantially parallel fiber-receiving grooves, the
30 grooved member also consisting substantially of material having a modulus of elasticity substantially greater than the modulus of the fiber-contacting material, e.g., a molded plastic member.

35 The cover member typically comprises means for introducing index-matching material between the end faces of the fibers held in the grooves, and the substrate can comprise means for supplying air suction to the grooves, to

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urge the fibers into the grooves during the process of making the connection.

The inventive connector can advantageously be used to connect linear arrays of fibers, e.g., ribbon cable, but is not so limited, since it can also be used to connect a single fiber pair, as well as to connect fibers from stranded multifiber cables. It can be used to provide temporary connections, as may be desirable in case of damage to a fiber cable, or to provide permanent connections. Furthermore, it can be used to connect long haul fibers, or to connect fibers in local area networks (LAN) or other relatively short haul applications. It is advantageously used to connect multimode fibers, but is not so limited.

Disclosed is also a combination comprising a first optical fiber cable comprising at least a first optical fiber, a second optical fiber cable comprising at least a second optical fiber, and an optical fiber connector, the first optical fiber and the second optical fiber secured to the optical fiber connector, with the optical fiber connector being of the above-described type. In the combination according to the invention, a portion of the first optical fiber and a portion of the second optical fiber are positioned in a fiber-receiving groove such that an end of the first optical fiber is facing an end of the second optical fiber. Preferably the ends are maintained spaced apart, advantageously between about 10^{-4} and about 10^{-3} inches ($2.5\text{ }\mu\text{m}$ to $25\text{ }\mu\text{m}$) apart at 25°C , with index-matching material substantially filling the space between the fiber ends. The index-matching material advantageously has a relatively low elastic modulus, typically less than one-tenth the elastic modulus of the optical fiber material, preferably less than about 10^3 psi (6.9 MPa), measured at 25°C .

The inventive combination can have advantageous properties. For instance, exemplary combinations have had less than 0.1 dB excess loss over the temperature range

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-40°C to 77°C. "Excess connector loss" herein is the connector loss at a given temperature minus the connector loss at 25°C.

Unless stated otherwise, numerical parameter values herein are the values at 25°C.

Brief Description of the Drawings

FIG. 1 shows substrate and cover of an exemplary connector according to the invention;

FIG. 2 schematically depicts an exemplary connector in cross section;

FIG. 3 shows an exemplary connector in exploded view;

FIG. 4 schematically depicts a further connector according to the invention; and

FIG. 5 shows an exemplary computed curve of the gripping force on a fiber vs. the elastic modulus of the fiber-contacting compliant material.

Identical or analogous features are designated with the same numerals in different Figures.

Detailed Description

A principal aspect of the inventive connector is the use of a cover member comprising compliant material in contact with optical fibers confined between the substrate and the cover member. Typically, the cover member comprises a relatively rigid backing member, with a layer of compliant material adhering thereto. Use of this compliant layer leads to improved connector characteristics, as compared to prior art connectors lacking the compliant layer.

Typically, both the fiber-receiving grooves in the substrate and the fibers themselves are produced to be within specified limits of nominal design values. A result of these permissible (and unavoidable) departures from the nominal design is a variation in the amount that fibers extend above the substrate surface, resulting, in prior art connectors, in unequal loading forces on different fibers within the connector. For instance, the

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presence of a slightly oversized fiber may prevent the gripping of a smaller nearby fiber, if both substrate and cover are made of rigid material. The use of a compliant intermediate layer can insure that all fibers are properly seated in the substrate grooves, the compliant material acting to compensate for warping or other flaws in the splice cover or substrate, and use of appropriately chosen compliant material can ensure that sufficient normal force to prevent slippage is applied to each fiber.

FIG. 5 shows the calculated relationship between the elastic modulus of the compliant material and the normal force resulting on the smallest fiber in an array of fibers, with the smallest fiber assumed located adjacent to the largest fiber in the array, the difference in fiber diameters assumed to be the largest difference allowed under the specifications for a certain commercially available 125 μm diameter multimode fiber ($\pm 2 \mu\text{m}$). FIG. 5 is exemplary only, since the details of the relationship between modulus and force obviously depend on the assumptions used, including the allowable fiber diameter variations, and the force urging the cover towards the substrate. However, FIG. 5 clearly shows that the gripping force has a maximum value at some intermediate modulus value, in the exemplary case at a modulus of about 5,000 psi.

The modulus of elasticity is not the only parameter of the fiber-contacting material that is of interest. The surface of the compliant member should have significant friction, typically an effective coefficient of friction of at least about 0.25, with the optical fibers in contact therewith. If desired, a compliant member having a "sandpaper" surface structure can be used. This typically increases the effective coefficient of friction. For instance, we have used polyester films with 1-8 μm SiC particles adhering to the surface. Particles could of course also be embedded in the material so as to protrude, at least partially, from the surface.

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A further significant aspect of connectors according to the invention is their potential for low added loss during temperature cycling. Analysis of a model of the connector indicates that, at temperatures other than the temperature (T_0 , typically about 25°C) at which the connection was originally made, the longitudinal stress in the splice interface region is proportional to the elastic modulus of the material between the fiber end faces (typically index-matching material), and inversely proportional to the gap between the fiber end faces at T_0 . The stress is also a function of the differences between the thermal expansion coefficients of the fiber, the substrate, and the interface material. The analysis suggests that it is advantageous to use interface material having a relatively low elastic modulus, typically less than one-tenth of the elastic modulus of the optical fiber material, preferably less than about 6.9 MPa at 25°C. We have, for instance, used silicon gel index-matching material (GE 6159, RTV silicone gel, available from the General Electric Company).

The analysis also suggests that it is advantageous to have finite spacing between the fiber end faces at T_0 , typically between about 2.5 μm and about 25 μm , and that the fiber gripping length advantageously is kept to a minimum, consistent with the longitudinal load requirements. In an exemplary design the gripping length was about 5 mm.

We will next describe an exemplary and preferred embodiment of the invention. FIG. 1 shows a connector 10 comprising grooved substrate 11 and cover 12. The substrate comprises a multiplicity (e.g., 12) of fiber-receiving grooves 13, typically having basically triangular or trapezoidal cross section, of a size and depth to ensure that the fibers extend above grooved substrate surface 19. The substrate also comprises vacuum openings 15 which are used to supply air suction to the fibers, whereby movement of the fibers into the grooves is

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assisted, and the fibers are maintained in their respective grooves during connector assembly. Cover 12 comprises a raised portion 190, with a layer of compliant material 14 thereon. Slot 16 permits introduction of index-matching material during or after connector assembly. Interlocking members 17 and 18 serve to provide initial alignment between substrate and cover. Both ends of both substrate and cover are shaped to permit insertion of the members into a cable termination member, to be shown below, with ridges 191 permitting locking of the cable termination members to the connector members. In this preferred embodiment both substrate and cover are glass-filled molded plastic parts. In particular, we used, inter alia, RYTON, a polyphenylene sulfide available from Phillips Petroleum Company of Bartlesville, Oklahoma. This material has a modulus of elasticity of about 1.2×10^6 psi.

FIG. 2 schematically shows a cross-sectional view of an assembled connector according to the invention. Optical fiber ribbon 20 comprises optical fibers 21 and protective material, the protective material being removed from a portion of the ribbon. Stripped fibers 21 are placed into the fiber-receiving grooves in substrate 11, such that the end faces of the fibers are facing each other, the interface located near the center line of the substrate. Cover 12, with compliant material 14 adhering to raised portion 190 of the cover, is placed onto the substrate, thereby confining the fibers. Vacuum openings 15 are used to apply suction to the fibers during assembly. Two elastic clips 22 urge the cover towards the substrate, thereby providing fiber gripping force. The cover comprises slot 16 for introducing index matching material 23 into the fiber joint region, including the space between the opposed fiber end faces. Index matching material is advantageously introduced after assembly of the connector, to prevent its wetting of contacting surfaces.

FIG. 3 schematically shows an exploded view of a substantially complete optical fiber ribbon connector.

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according to the invention. An end of ribbon 20 is inserted into ribbon terminus piece 31, the protective material stripped from an appropriate length of the optical fiber ribbon, the fibers scribed and broken (and/or polished), by means known to those skilled in the art such as to be of substantially equal length, and the fibers 21 placed into the fiber-receiving grooves of substrate 11, preferably by means of air suction provided through 15 by vacuum generating means not shown. The substrate center line is marked by marker 33, and the fiber ends are to be positioned, typically with the aid of a microscope, so as to be substantially at the substrate center line with, e.g., about 12 μm between the fiber end faces. After placing cover 12 atop the substrate, and sliding spring fasteners 22 over cover and substrate such that the fasteners contact the cover at loading ridges 32, index-matching material is introduced into slot 16, and the connector assembly inserted into ribbon termination pieces 31; such that ridges 191 are resting in cut-outs 34, providing strain relief for flexing forces.

As indicated previously, the above embodiment, although preferred, is exemplary only. A different exemplary embodiment is shown in FIG. 4. The substrate comprises a backing member 40, e.g., an INVAR plate, with a grooved member 41 thereon. (INVAR is the trademark for a well-known alloy having low thermal expansion.) A grooved member can be molded plastic, or any other appropriate material, e.g., a silicon chip with grooves etched therein. Two substantially identical cover members, each comprising a backing member 43, e.g., an INVAR member with a loading ridge 44 thereon, and compliant layer 42, are pressed against fibers 21 and the substrate surface by means of spring fasteners 22. As described above, fiber-protective material is removed from an appropriate length of fiber ribbon cable 20, the exposed fibers trimmed and placed into the fiber-receiving grooves of the substrate, held in place by means of cover members and spring

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fasteners, with the fiber junction 45 coated with index matching material, e.g., a UV curable adhesive of appropriate refractive index, which can also enhance fiber gripping. Adhesive 46 serves to establish a strong bond
5 between the connector members and the fiber ribbons, thereby providing strain relief.

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Claims

1. Optical fiber connector comprising
- a) a substrate comprising at least one fiber-receiving groove adapted for receiving therein a portion of a first fiber and a portion of a second fiber, with an end of the first fiber facing an end of the second fiber;
- b) at least one cover member comprising material which is to be in contact with at least the first fiber, the material to be termed fiber-contacting material; and
- c) cover-securing means adapted for urging the cover member towards the substrate, whereby the fiber-contacting material is maintained in contact with at least the first fiber;

CHARACTERIZED IN THAT

- d) the fiber-contacting material has a modulus of elasticity that is less than about 6.9 GPa at 25°C.

2. Connector of claim 1, wherein the substrate comprises a multiplicity of substantially parallel, spaced fiber-receiving grooves.

3. Connector of claim 2, the cover member comprising a backing member comprising material having a modulus of elasticity greater than the modulus of elasticity of the fiber-contacting material, the fiber-contacting material adhering to the backing member and to be in contact with both the first and the second fibers.

4. Connector of claim 3, wherein the substrate comprises a grooved member comprising the multiplicity of fiber-receiving grooves, the grooved member material having a modulus of elasticity greater than the modulus of elasticity of the fiber-contacting material.

5. Connector of claim 3, the cover member comprising means for introducing an index-matching material between the ends of the first and of the second fiber.

6. Connector of claim 3, wherein the fiber-contacting material has an effective coefficient of friction with the first optical fiber of at least 0.25 at

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25°C.

7. Connector of claim 6, wherein the fiber-
contacting material comprises friction-enhancing particles,
the particles adhering to the fiber-contacting material
5 surface or being at least partially embedded in the fiber-
contacting material.

8. Connector of claim 3, wherein the substrate
comprises means for supplying air suction to the grooves to
urge the fibers into the grooves.

10 9. Connector of claim 4, wherein the grooved
member is a molded plastic member.

10. Connector of claim 4, wherein the grooved
member is produced by a process comprising etching of the
grooves.

15 11. Connector of claim 1 comprising two cover
members, each comprising fiber-contacting material having a
modulus of elasticity less than about 6.9 GPa at 25°C.

12. In combination, a first optical fiber cable
comprising at least a first optical fiber, a second optical
20 fiber cable comprising at least a second optical fiber, and
an optical fiber connector, the first optical fiber and the
second optical fiber secured to the optical fiber
connector, the optical fiber connector comprising

a) a substrate comprising at least one fiber-
25 receiving groove, a portion of the first optical fiber and
a portion of the second optical fiber positioned in the
groove such that an end of the first optical fiber is
facing an end of the second optical fiber;

b) at least one cover member comprising material
30 which is in contact with at least the first fiber, the
material to be referred to as fiber-contacting material;
and

c) cover-securing means adapted for urging the
cover member towards the substrate, whereby the fiber-
35 contacting material is maintained in contact with at least
the first fiber;

CHARACTERIZED IN THAT

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d) the fiber-contacting material has a modulus of elasticity that is less than about 6.9 GPa at 25°C.

13. Combination of claim 12, the substrate comprising a member comprising thereon a multiplicity of substantially parallel, spaced fiber-receiving grooves, the member to be referred to as the grooved member, the grooved member material having a modulus of elasticity greater than the modulus of elasticity of the fiber-contacting material.

14. Combination of claim 13, the cover member comprising a backing member comprising material having a modulus of elasticity greater than the modulus of elasticity of the fiber-contacting material, the fiber-contacting material adhering to the backing member.

15. Combination of claim 14, the fiber-contacting material being in contact with the first and with the second optical fiber.

16. Combination of claim 12, the end of the first optical fiber spaced from the end of the second optical fiber, the distance between the ends being at least about 2.5 μm at 25°C, with index-matching material substantially filling the space between the fiber ends.

17. Combination of claim 16, wherein the cover member comprises means for introducing the index-matching material.

18. Combination of claim 17, the index-matching material and at least the first optical fiber having elastic moduli, with the modulus of the index-matching material being less than one tenth of the first optical fiber elastic modulus, both measured at 25°C.

19. Combination of claim 12, wherein the fiber-contacting material has an effective coefficient of friction with the first optical fiber of at least 0.25 at 25°C.

20. Combination of claim 19, wherein the fiber-contacting material comprises friction-enhancing particles, the particles adhering to the fiber-contacting material surface, or being at least partially embedded in the fiber-

- 13 -

contacting material.

21. Combination of claim 15, wherein the grooved member is a molded plastic member.

22. Combination of claim 21, wherein the backing member and the substrate consist substantially of molded plastic.

23. Combination of claim 12, wherein the connection between the first optical fiber and the second optical fiber has a loss, the loss at any temperature in the range from -40°C to $+77^{\circ}\text{C}$ being at most 0.1 dB greater than the loss at 25°C .

24. Combination of claim 12, wherein the fiber-contacting material modulus of elasticity is at most 0.69 GPa at 25°C .

25. Combination of claim 12, wherein at least the first optical fiber cable is a ribbon cable.

26. Combination of claim 18, wherein the index-matching material elastic modulus is at most 6.9 MPa at 25°C .

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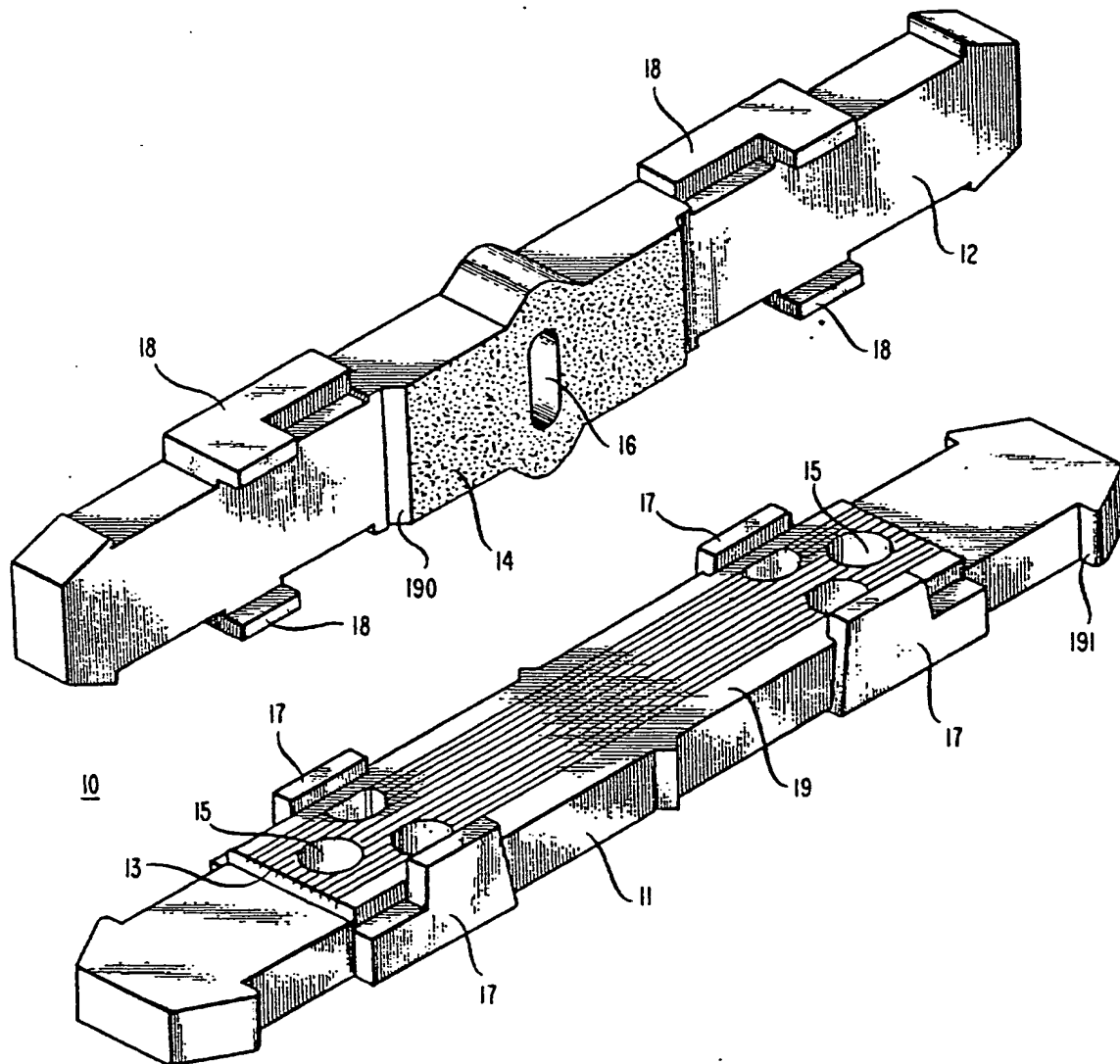
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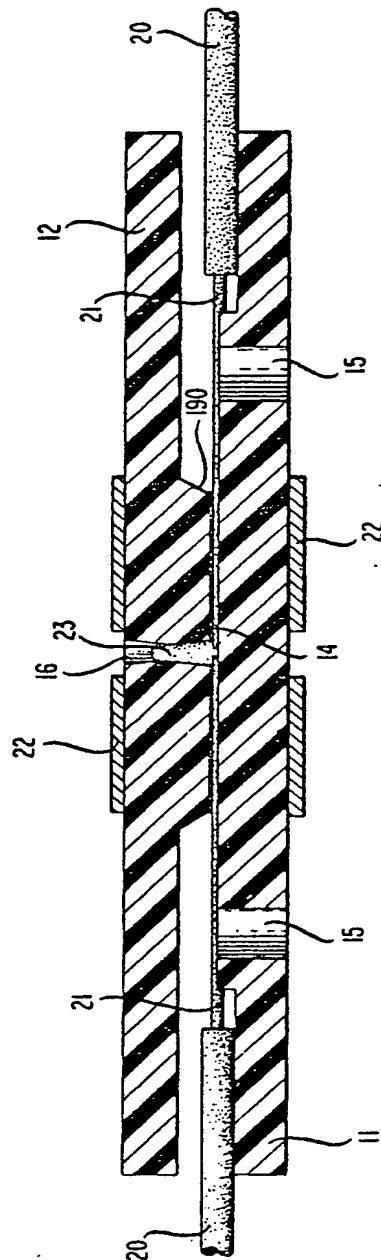
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FIG. 1

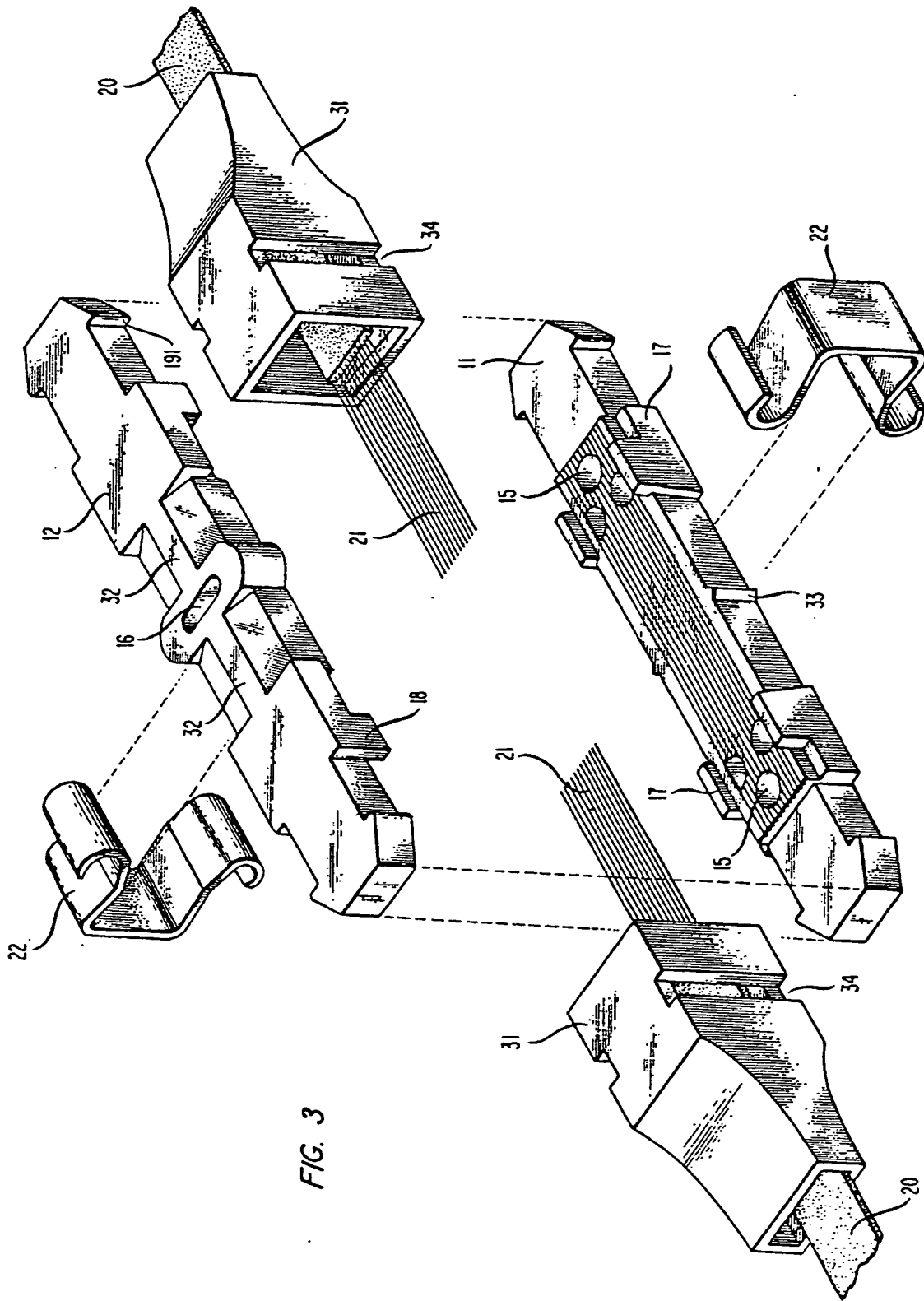


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FIG. 2



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FIG. 4

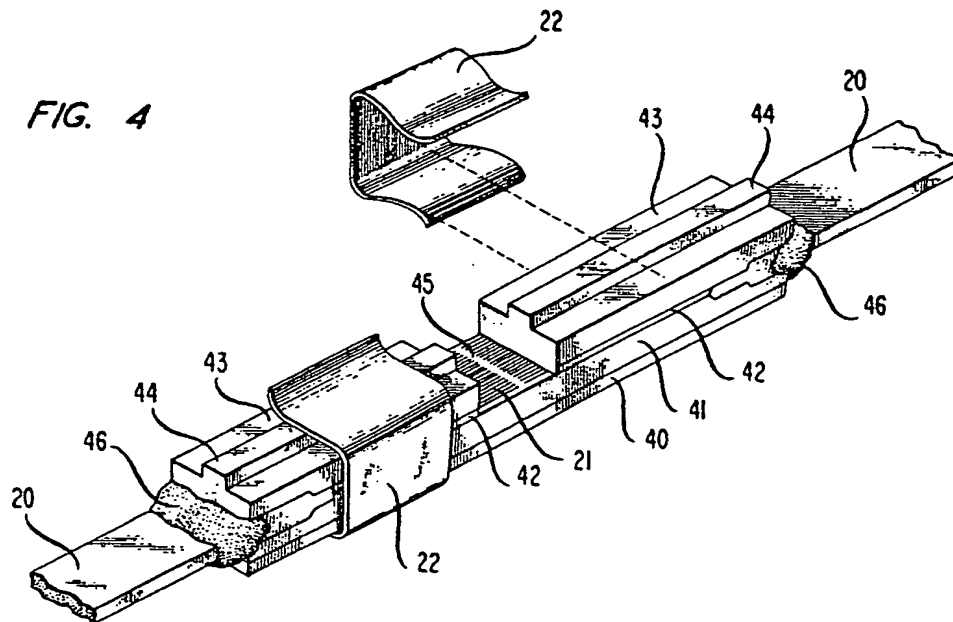
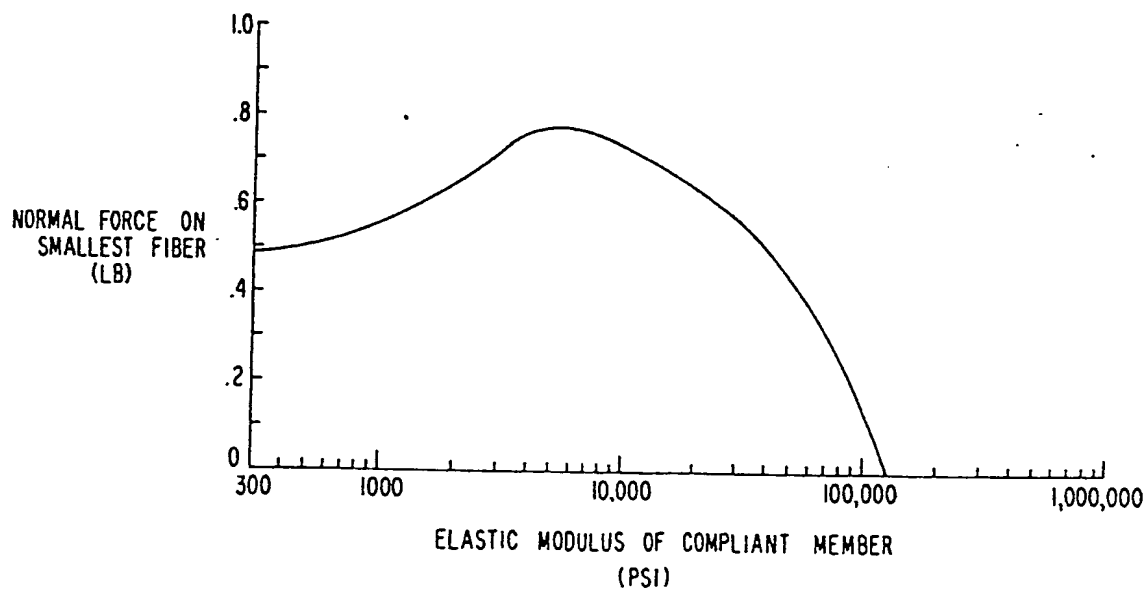


FIG. 5



INTERNATIONAL SEARCH REPORT

International Application No PCT/US 85/01461

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) *

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC⁴: G 02 B 6/38

II. FIELDS SEARCHED

Minimum Documentation Searched ⁷

Classification System

Classification Symbols

IPC⁴

G 02 B

Documentation Searched other than Minimum Documentation
to the Extent that such Documents are Included in the Fields Searched *

III. DOCUMENTS CONSIDERED TO BE RELEVANT *

Category *	Citation of Document, ¹¹ with Indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³
A	US, A, 4146301 (A.H. CHERIN) 27 March 1979, see column 3, line 35 - column 5, line 56; figures 1-5A (cited in the application) --	1,2,5,8,9, 11-13,16,22 25
A	US, A, 4028162 (A.H. CHERIN) 7 June 1977, see column 2, line 13 - column 3, line 5; figures (cited in the application) --	1,2,12,13, 16,25
A	Review of the Electrical Communication Labor- atories, volume 32, nr. 4, July 1984, Tokyo, (JP) pages 676-683 N. Kashima et al.: "Splicing and Connect- ing Techniques for Optical Subscriber Cables", see page 678, column 1; figures 5,6 --	1,2,12,13, 25
A	IEEE Global Telecommunications Conference, volume 1, B1.4.1, 29 November - 2 Decem- ber 1982, Miami, (US) N.E. Hardwick III et al.: "Design for Rapid Lightguide Restoration", see chapter 2; 2.1; figures 2,3	1,2,5,12,13, 25

* Special categories of cited documents: ¹⁰

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cannot be considered to involve an inventive step when the
document is combined with one or more other such docu-
ments, such combination being obvious to a person skilled
in the art.

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IV. CERTIFICATION

Date of the Actual Completion of the International Search

7th November 1985

Date of Mailing of this International Search Report

26 NOV 1985

International Searching Authority

EUROPEAN PATENT OFFICE

Signature of Authorized Officer

G.L.M. Kruidenberg

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
Category *	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No
A	Ninth European Conference on Optical Communication-ECOC '83, Geneva, (CH), 23-26 October 1983, Elsevier, Amsterdam, (NL) P. Jaccard et al.: "A Batch Fabrication Technique for Single Mode Fiber Couplers", see abstract; figures 3,4	10,25
A	Patents Abstracts of Japan, volume 5, nr. 32, 27 February 1981, page 50 & JP, A, 55156908 (NIPPON DENSHIN DENWA KOSHA) 6 December 1980, see the whole document	1,12
A,P	US, A, 4475790 (R.G. LITTLE) 9 October 1984, see abstract; figures 4,6	1,2,10,12,13

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON

INTERNATIONAL APPLICATION NO.

PCT/US 85/01461 (SA 10390)

This Annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on 20/11/85

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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A- 4146301	27/03/79	None	
US-A- 4028162	07/06/77	US-A- 3912574 CA-A- 1022740	14/10/75 20/12/77
US-A- 4475790	09/10/84	None	

For more details about this annex :
see Official Journal of the European Patent Office, No. 12/82